1DS

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : C23C 14/56

A1

(11) International Publication Number: WO 97/28290

(43) International Publication Date: 7 August 1997 (07.08.97)

(21) International Application Number: PCT/US97/00654

(22) International Filing Date: 16 January 1997 (16.01.97)

(30) Priority Data:
08/594,907 31 January 1996 (31.01.96) US

(71) Applicant: OPTICAL COATING LABORATORY, INC. [US/US]; 2789 Northpoint Parkway, Santa Rosa, CA 95407-7397 (US).

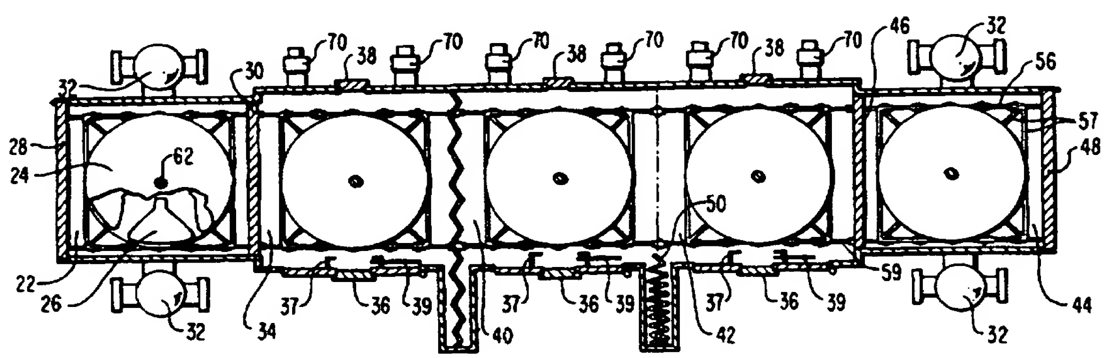
(72) Inventors: SEDDON, Richard, I.; 2245 Cummings Drive, Santa Rosa, CA 95404 (US). KURMAN, Eric, W.; 509 Matheson Street, Hearldsburg, CA 95448 (US). SEESER, James, W.; 1115 Hulen Drive, Columbia, MO 65203 (US). IMUS, Mark; P.O. Box 582, Sausalito, CA 94966 (US).

(74) Agents: SEELEY, David, O. et al.; Workman, Nydegger & Seeley, 1000 Eagle Gate Tower, 60 East South Temple, Salt Lake City, UT 84111 (US).

(81) Designated States: JP, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: MULTI-CHAMBER CONTINUOUS SPUTTER COATING SYSTEM



(57) Abstract

Methods and apparatus are disclosed for effecting high rate deposition and formation of thin films onto substrates (26) mounted on rotating drums (24) transported sequentially into, through, and out of continuously operating processing chambers (34, 40, 42) maintained under appropriate vacuum conditions. Within each processing chamber (34, 40, 42), the drums (24) rotate the substrates (26) past atmospherically separated linear magnetron sputter deposition and reaction zones to deposit and form durable optical quality thin film coatings. Serially connected to the at least one processing chamber (34, 40, 42) is at least one load chamber (22), which may be sealed from the atmosphere and from the processing chamber (34, 40, 42). Also serially connected to the at least one processing chamber (34, 40, 42) is at least one unload chamber (44) sealable from the atmosphere and the processing chamber (34, 40, 42). The pressure within the at least one load (22), unload (44) and processing chambers (34, 40, 42) is selectively cycled so as to permit sequential introduction of substrate-carrying drums.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgystan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic			SE	Sweden
CG	Congo	KR	Republic of Korea	SG	Singapore
CH	Switzerland	KZ	Kazakhstan	SI	Slovenia
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovakia
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CN	China	LR	Liberia	SZ	Swaziland
CS	Czechoslovakia	LT	Lithuania	TD	Chad
CZ	Czech Republic	LU	Luxembourg	TG	Togo
DE	Germany	LV	Latvia	TJ	Tajikistan
DK	Denmark	MC	Monaco	TT	Trinidad and Tobago
EE	Estonia	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	UG	Uganda
FI	Finland	ML	Mali	US	United States of America
FR	France	MN	Mongolia	UZ	Uzbekistan
GA	Gabon	MR	Mauritania	VN	Viet Nam

MULTI-CHAMBER CONTINUOUS SPUTTER COATING SYSTEM

BACKGROUND OF THE INVENTION

1. Technical Field:

The present invention is directed to methods and apparatus for effecting high rate deposition and formation of thin films onto substrates mounted on rotating drums transported sequentially into, through, and out of continuously operating processing chambers maintained under appropriate vacuum conditions. Within each processing chamber, the drums rotate the substrates past atmospherically separated linear magnetron sputter deposition and reaction zones to deposit and form durable optical quality thin film coatings.

2. Background Information:

Reactive sputtering has long been used as a method of choice for effecting the deposition of various materials in order to form a thin film on a substrate. DC magnetron reactive sputtering has been developed in recent years as a technique for producing layers of dielectric materials, such as metal oxides, and oxide semiconductors, such as indium tin oxide. The DC magnetron reactive sputtering technique has advantages over other techniques such as RF magnetron sputtering of dielectric materials in that deposition speed gains can be realized, and production equipment is less costly, safer, and easier to control.

Particularly useful and effective methods and apparatus for DC reactive sputtering are disclosed in United States Patent No. 4,851,095 and in related U.S. Patent No. 5,225,057, which patents are incorporated herein by reference in their entireties. Patent No. 4,851,095 teaches the use of a metal mode reactive sputtering process which offers a dramatic advancement in thin film deposition technology, providing enhancements such as the ability to deposit uniform coatings onto complex shaped substrates and exceptionally fast reactive deposition processing. In addition, Patent No. 4,851,095 teaches how to deposit multiple layers of one or more materials within a single processing chamber wherein both deposition and reaction are effected in long narrow axial zones adjacent the periphery of a moving substrate carrier. Patent No. 4,851,095 utilizes a rotating drum for carrying substrates to be coated past one or more metal sputtering cathodes. Oxidation reactions may also be performed through use of suitable cathodes. Both deposition and reaction are constrained to long narrow vertical zones adjacent the periphery of the rotating drum, which moves the desired substrate past such zones at a controlled rate so that a uniform thin film will be deposited.

Patent No. 5,225,057 specifically teaches the selective control of coating thickness with respect to curved substrates processed in accord with methods and apparatus of Patent 4,851,095. The thickness of a thin film from the center to the edge of a curved substrate is controlled such that either a varied or a constant thickness is achieved depending on the desired optical performance.

Although a significant improvement over prior art systems, the process of Patent No. 4,851,095 suffers from the drawback that a substantial amount of time is utilized in setting the system up for each deposition and formation processing sequence. This is because several steps are involved in utilizing the thin film deposition and formation process of Patent No. 4,851,095 in addition to the actual deposition and formation of the thin film within the processing chamber itself.

Initially, the substrate to be coated is mounted onto the periphery of the drum and the drum is loaded into the processing chamber. Next, the pressure within the processing chamber must be reduced to very low pressures, typically about 1×10^{-6} torr. The metal sputtering cathodes are then activated by initiating the flow of sputter gas and applying power to the cathodes. Only after the cathodes have been brought to stable operating conditions can the desired deposition and formation sequence be initiated. Finally, after the deposition and formation processing is complete, the pressure is returned to atmospheric and the drum is removed from the processing chamber.

The entire operation from commencement of loading of the drum into the processing chamber until completion of unloading of the drum from the processing chamber may typically take about an hour. Of this time, only about thirty minutes may be involved in actual deposition and formation of the thin film, with the remaining thirty minutes being consumed by the steps of loading the drum from the processing chamber, initiating the vacuum, activating the cathodes and establishing stable conditions for operation of the cathodes, and, finally, returning atmospheric pressure for unloading of the drum. Hence, a typical operation is only able to effect actual deposition and formation of thin films about half the time that the equipment is in operation. Because the equipment necessary to practice the invention of Patent No. 4,851,095 is extremely expensive, a 50% operation rate puts significant limits on how economically the process can be operated.

SUMMARY OF THE INVENTION

In accordance with the invention as embodied and broadly described herein, the present invention is directed to methods and apparatus for effecting high rate deposition and formation of thin films onto substrates mounted on rotating drums transported

maintained under appropriate vacuum conditions. Serial connection of the processing chambers with load and unload chambers permits maintenance of the continuous vacuum conditions required for the continuous stable operation of the thin film deposition and formation processing chambers.

The presently preferred apparatus of the invention advantageously includes at least one processing chamber which is configured so as to be capable of receiving a rotatable drum mounted with at least one substrate which is to be coated with a thin film. Within each processing chamber, the drum rotates the substrates past atmospherically separated linear magnetron sputter deposition and reaction zones to deposit and form durable optical quality thin film coatings. Additional processing chambers may be provided such that the deposition and formation of thin films on the substrate may occur through sequential steps within serially connected processing chambers. Pumps are provided for establishing and maintaining a suitable vacuum within the at least one processing chamber.

The apparatus also includes at least one load chamber serially connected to the at least one processing chamber and at least one unload chamber also serially connected to the at least one processing chamber. Each of the at least one load chamber and the at least one unload chamber are provided with pressure seals which are used for sealing the load and unload chambers from the ambient external atmosphere and for sealing the load and unload chambers from the vacuum atmosphere within the at least one processing chamber. Each of the load and unload chambers are provided with suitable pumps capable of cycling the pressure within the chambers between the pressures required to introduce and remove the drums into and out of the at least one processing chamber.

The pressures within the load and unload chambers are cycled so as to permit introduction of drums carrying substrate into the at least one load chamber and to coordinate with the sequential advancement of drums and substrate through the at least one processing chamber and from the processing chamber into the at least one unload chamber while the desired operating vacuum pressure is continuously maintained within the at least one processing chamber. Additional load and unload chambers may be provided in serial communication with each other such that the loading of the substrate-carrying drums may occur in sequential steps through serially connected load chambers and the unloading of the substrate-carrying drums may occur in sequential steps through serially connected unload chambers. In this manner, each load and unload chamber is required to cycle through only a portion of the pressure change from within the at least one processing chamber to the ambient external environmental pressure thus reducing the time required and the amount of work performed by the pumps within each load or unload

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, which represent the best mode presently contemplated for carrying out the present invention:

Figure 1 is a perspective view of a schematic representation of a preferred apparatus for carrying out the present invention, with a portion broken away.

Figure 2 is a cross-sectional view taken along lines 2-2 of Figure 1.

Figure 3 shows a cross-sectional view similar to that of Figure 2 of a schematic representation of an alternative presently preferred apparatus for carrying out the present invention.

Figure 4 shows a cross-sectional view taken along lines 4-4 of Figure 1.

Figure 5 is an exploded top view of a portion of a preferred apparatus for carrying out the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention is directed to methods and apparatus for effecting high rate deposition and formation of thin films onto substrates mounted on rotating drums transported sequentially into, through, and out of continuously operating processing chambers maintained under appropriate vacuum conditions. Serial connection of the processing chambers with load and unload chambers permits maintenance of the continuous vacuum conditions required for the continuous stable operation of the thin film deposition and formation processing chambers. The present invention incorporates and builds upon the teachings found in United States Patents No. 4,851,095 and No. 5,225,057. Many specific details regarding the sputtering process and apparatus which are not separately addressed herein may be ascertained by reference to those patents, which are incorporated herein by reference. It is to be understood, however, that the present invention is not to be limited by the teachings of those patents. Other types of sputtering devices may, for example, be used in the practice of the present invention.

Patent No. 4,851,095 describes DC magnetron reactive sputtering methods and apparatus which utilize multiple deposition and reaction sputtering devices to deposit thin films onto a variety of substrates, including substrates having complex shapes. Patent No. 4,851,095 utilizes a rotating drum for carrying substrates past atmospherically separated linear magnetron sputter deposition and reaction zones to deposit and form durable optical quality thin film coatings. In addition, Patent No. 4,851,095 teaches how to deposit multiple layers of one or more materials within a single processing chamber wherein both deposition and reaction are effected in long narrow axial zones adjacent the periphery of

number of combinations of multi-layer coatings to be formed onto various substrates utilizing a plurality of cathodes is provided.

Patent No. 5,225,057 specifically teaches the selective control of coating thickness with respect to curved substrates processed in accord with the methods and apparatus of Patent 4,851,095. The thickness of a thin film from the center to the edge of a curved substrate is controlled such that either a varied or a constant thickness is achieved depending on the desired optical performance.

Although a significant improvement over prior art systems, the process of Patent No. 4,851,095 suffers from the drawback that a substantial amount of time is utilized in preparation of the processing chamber and loading and unloading of the substrate carrier. This is because several steps are involved in the sputtering process of Patent No. 4,851,095 in addition to the actual deposition of material. As was noted above, only about half of the time required to complete deposition and formation of a typical thin film onto a substrate using the processing apparatus and method of Patent 4,851,095 is actually spent in the sputtering operation. The other half of the time is involved in activities such as introducing the substrate-carrying drum into the processing chamber; lowering the pressure in the processing chamber to a desired vacuum; activating and establishing stable conditions for operation of the sputtering cathodes; raising the pressure in the processing chamber back to atmospheric pressure upon completion of the deposition and formation sequence; and removing the drum and substrate from the processing chamber. The present invention provides substantial improvements over Patent No. 4,851,095 by greatly increasing the amount of time spent in the actual deposition of material onto the substrate in comparison to time spent preparing the processing chamber and loading and unloading the processing chamber.

In order to obtain these benefits, it is a feature of the present invention to advance a drum supporting substrate upon which a thin film is to be deposited sequentially through the apparatus in a manner which isolates the processing chamber on a continuous basis from the atmosphere. This permits a vacuum to be maintained for extended periods after it is initially established in the processing chamber. It also permits the sputtering cathodes and ion sources, if any, to be maintained at stable operating conditions for extended periods. Once the proper operating conditions have been established, the present invention provides for the successive introduction of drums bearing substrate on a continuous basis, without the requirement to cycle between atmospheric pressure and vacuum within the processing chambers, and without repetitive activation and deactivation of the sputtering cathodes and ion sources.

Figures 1 and 2 illustrate one presently preferred embodiment of the present invention in a simplified schematic form. Figure 1 is a perspective view of a serial sputter coating system 20, with a portion at one end broken away. Figure 2 is a horizontal cross-sectional view of serial sputter coating system 20 taken along the line 2-2 of Figure 1.

The presently preferred apparatus of the invention advantageously includes at least one processing chamber which is configured so as to be capable of receiving a rotatable drum mounted with substrate which is to be coated with a thin film. Additional processing chambers may be provided such that the deposition and formation of thin films on the substrates may occur through sequential steps within serially connected processing chambers. Pumps are provided for establishing and maintaining a suitable vacuum within the at least one processing chamber.

The apparatus also includes at least one load chamber serially connected to the at least one processing chamber and at least one unload chamber also serially connected to the at least one processing chamber. Each of the at least one load chamber and the at least one unload chamber are provided with pressure seals which are used for sealing the load and unload chambers from the ambient external atmosphere and for sealing the load and unload chambers from the vacuum atmosphere within the at least one processing chamber. Each of the load and unload chambers are provided with suitable pumps capable of cycling the pressure within the chambers between the pressures required to introduce and remove the drums into and out of the at least one processing chamber.

The pressures within the load and unload chambers are cycled so as to permit introduction of drums carrying substrate into the at least one load chamber and to coordinate with the sequential advancement of drums and substrate through the at least one processing chamber and from the processing chamber into the at least one unload chamber while the desired operating vacuum pressure is continuously maintained within the at least one processing chamber. As described below with reference to Figure 3, additional load and unload chambers may be provided in serial communication with each other such that the loading of the substrate-carrying drums may occur in sequential steps through serially connected load chambers and the unloading of the substrate-carrying drums may occur in sequential steps through serially connected unload chambers. In this manner, each load and unload chamber is required to cycle through only a portion of the pressure change from within the at least one processing chamber to the ambient external environmental pressure thus reducing the time required and the amount of work performed by the pumps within each load or unload chamber.

By reference to Figure 2, it will be seen that serial sputter coating system 20 of the

for loading, processing, and unloading the substrate-carrying drums. Beginning at the left of Figure 2, the first of these chambers is load chamber 22. Load chamber 22 is sized so as to be capable of receiving a rotatable drum 24 loaded with a substrate 26 which is to be treated by deposition and formation of a thin film. In Figures 1 and 2, the substrate comprises a plurality of cathode ray tubes, although it will be appreciated that many other substrates may be used. Load chamber 22 is provided with a door 28 which can be opened to permit entry of a drum 24 into the load chamber. Load chamber 22 is also provided with a second door 30. Both doors 28 and 30 are adapted to provide pressure seals so that the pressure inside load chamber 22 may be reduced to vacuum conditions using one or more vacuum pumps 32. Some of the pumping may preferably be provided by cryo coils (not shown).

Adjacent to load chamber 22 is a first processing chamber 34. Processing chamber 34 is provided with at least one magnetron enhanced sputtering device, such as described in Patent No. 4,851,095, which is capable of depositing a thin layer of a desired substance onto the substrate as the drum rotates the substrate past the sputtering device. The linear magnetron sputtering device comprises atmospherically separated linear magnetron sputter deposition and reaction zones. Figure 2 illustrates schematically the use of a sputtering cathode 36 within processing chamber 34 for depositing metal materials such as silicon, tantalum, titanium, iron, or other sputterable material capable of forming stable oxides. Processing chamber 34 is also shown as being provided with an ion source 38 capable of oxidizing the deposited thin films of the metal materials. As described in Patent No. 4,851,095, additional sputtering cathodes or ion sources may be included within the processing chamber, permitting a very large number of combinations of single or multi-layer coatings to be obtained. As described for load chamber 22, the processing chambers also comprise means for establishing and maintaining the desired vacuum conditions such as vacuum pumps or cryo coils (not shown). In addition, as described further with respect to Figure 5, pumps 70 are preferably positioned such that excess oxygen can be rapidly and completely removed from the vicinity of ion source 38. Baffles (shown in Figure 5) may also be used to further isolate the atmosphere surrounding the ion source. The sputtering cathode 36 is preferably placed in a box 37 having a sliding shutter 39 to permit burndown of the cathode between applications of sputtered layers.

It is a feature of the present invention that additional processing chambers may be utilized rather than a single processing chamber. Figure 2, for example, shows the use of second and third processing chambers 40 and 42, each of which is likely to be identical to the first processing chamber, although each processing chamber may have different

Regardless whether there is one or a plurality of processing chambers, the last processing chamber is followed by an unload chamber. In Figure 2, unload chamber 44 is located adjacent to third processing chamber 42, and is shown in a form which corresponds to load chamber 22. Unload chamber 44 includes first and second doors 46 and 48 which are capable of providing pressure sealing so that the pressure within the unload chamber may be cycled between atmospheric pressure and a vacuum independently of the pressure in the processing chambers. As with the load chamber, one or more pumps 32 are used to control the pressure within the unload chamber. Some of the pumping may preferably be provided by cryo coils (not shown).

It is a feature of the present invention that the pressure within the various processing chambers is maintained at a vacuum on a substantially continuous basis. For this reason, it is not deemed necessary to isolate each processing chamber from adjacent processing chambers in an air-tight manner. Rather, it is anticipated that relatively simple doors may be used to separate the processing chambers. Figure 2 illustrates schematically the presently preferred inclusion of accordion-type doors 50 which may be used as a barrier between adjacent processing chambers under circumstances where a barrier is useful. Alternatively, it may be appropriate to entirely dispense with any barrier between adjacent processing chambers.

Because each processing chamber is in pressure communication with adjacent chambers, it is not strictly necessary that each processing chamber be fitted with separate vacuum pumps. Accordingly, it is to be understood that even though some of the various processing chambers are illustrated in Figures 1 and 2 as being individually fitted with multiple pumps 32, such an arrangement is not necessary. One or more pumps may be located in any appropriate locations in order to initially establish the appropriate operating vacuum, and then maintain such vacuum during operation of the apparatus of the invention.

The system of Figures 1 and 2 provides significant advantages beyond the basic sputtering system described in Patent No. 4,851,095. In operation, door 30 separating the load chamber from first processing chamber 34 and door 46 separating unload chamber 44 from the last processing chamber 42 are both closed and sealed. Next, an operating vacuum, typically 1×10^{-4} or 1×10^{-5} torr, is established within the processing chambers through operation of the pumps serving those chambers. After a vacuum is established, the various cathodes and ion sources are activated and brought to stable operating conditions.

Load chamber 22 is brought to atmospheric pressure, if not already at that

and door 28 is closed and sealed. The pumps serving load chamber 22 are then operated in order to reduce the pressure within the load chamber to the same pressure as in the processing chambers. Door 30 is then opened, and the drum and substrate is advanced from the load chamber into the first processing chamber. Door 30 is then closed and sealed, and the pressure within load chamber 22 is brought back to atmospheric pressure. Door 28 is then opened to permit entry of another drum and substrate and the process of sealing the load chamber and lowering the pressure to match the pressure within the processing chamber is repeated.

Meanwhile, the drum within first processing chamber 34 is placed into rotational motion, and the cathodes and ion source are operated so as to effect processing of one or more sputtered layers onto the substrate. It is anticipated that treatment in the first processing chamber will be completed at about the same time that the vacuum is restored in the load chamber containing another substrate-carrying drum. At the appropriate time, door 30 is opened and the drum within the first processing chamber is advanced to the second processing chamber at the same time that the drum in the load chamber is advanced into the first processing chamber. As before, while the drums within both the first and second processing chambers are subjected to the thin film deposition and formation process, the pressure in the load chamber is returned to atmospheric, another substrate-carrying drum is introduced into the load chamber, and the pressure is again lowered to match the pressure within the processing chambers. At the completion of the processing period, door 30 is opened and the drums are again advanced as previously described.

The process of introducing substrate-carrying drums continues as described above until drums with substrate are located in each of the processing chambers. Unload chamber 44 is sealed and brought to the same pressure as the processing chambers. Door 46 is eventually opened to accept the drum advancing from processing chamber 42. Door 46 is then closed and sealed so that the pressure within unload chamber 44 may be brought to atmospheric pressure without affecting the vacuum within the processing chambers. At that point, door 48 is opened and the drum is unloaded from the apparatus of the invention. Door 48 is then reclosed and sealed, and vacuum reestablished in unload chamber 44 so that the process may be repeated and the next drum removed in turn.

From the foregoing, it will be appreciated that deposition and formation of thin films may be continued for extended periods without having to deactivate the sputtering cathodes or cycle the pressure within the processing chambers between operating vacuum conditions and atmospheric pressure.

It will also be appreciated from the foregoing that use of even a single processing chamber benefits from the advantages of using separate load and unload chambers to permit the desired vacuum and stable cathode operating conditions to be continuously maintained within the processing chamber. The advantages of multiple processing chambers in reducing the throughput time may be even more dramatic. For example, if sufficiently strong pumping action is available in connection with each of the load and unload chambers, it may be possible to cycle the pressure and introduce and withdraw the drums significantly faster than the time required to effect the thin film deposition and formation within the processing chambers. Under these conditions, the thin film deposition and formation process in a single chamber would impose a rate limit to the advancement of substrate-carrying drums from load chamber, to processing chamber, to unload chamber.

Spreading the thin film deposition and formation process among a plurality of processing chambers, however, permits a reduction of the rate limitation to the shortest time required for the deposition of the slowest single layer of material. For example, if a single layer of material requires five minutes to complete within a single processing chamber and two layers are desired for a particular substrate, approximately ten minutes are required to complete the deposition of the two layers utilizing a single processing chamber. This ten minute period becomes a rate-limiting step with respect to how fast a new drum may be introduced into the load chamber. On the other hand, if two processing chambers are used such that one layer is deposited and formed within each processing chamber, each chamber will require only five minutes. Ignoring for the moment the short interval required to move the drum between chambers, it will be appreciated that the use of two processing chambers would permit a new drum to be introduced into the load chamber approximately every five minutes.

It may be found in some situations that separating the thin film deposition and formation process among several processing chambers becomes more efficient than the capability to cycle the load and unload chambers between atmospheric pressure and operating vacuum conditions. Figure 3 depicts, in a simplified schematic form, another presently preferred embodiment of the present invention that is particularly useful in this type of situation.

The embodiment of Figure 3 is substantially identical to the embodiment of Figures 1 and 2, except that additional load and unload chambers have been added. In Figure 3, a first load chamber 152 is shown at the left, with a second load chamber 122 being shown adjacent to the first load chamber. A total of three processing chambers 134, 140 and 142

are shown next in sequence, just as in Figures 1 and 2, followed by first and second unload chambers 144 and 154.

In Figure 3, the function and operation of the two load chambers and two unload chambers are identical to those of the single load and unload chambers of Figures 1 and 2. However, the use of multiple load and unload chambers will shorten the time required in those chambers by splitting the task of cycling between atmospheric pressure and operating vacuum required during the loading and unloading processes. First load chamber 152, for example, need not be brought to operating vacuum conditions. It would be possible to utilize appropriate pumps to cycle the pressure in first load chamber 152 between atmospheric pressure and a selected intermediate vacuum, anticipated as typically being in the range of about 10 to 100 millitorr. The pressure in the second load chamber could then be cycled between the selected vacuum in the first load chamber and the operating vacuum required for deposition, anticipated as typically being in the range of about 1×10^{-4} to 1×10^{-5} torr.

It will be appreciated that these pressures are illustrative in nature. The most time-efficient approach will involve the selection of pressures and pumps so that cycling of pressures in both the first and second load chambers take substantially the same amount of time. If this is done, the actual amount of time required to introduce a new drum into first load chamber 152 will be nearly halved. For example, if it takes six minutes to cycle the pressure in load chamber 22 of Figure 2 between atmospheric pressure and operating vacuum and to load/advance a drum, it might be possible to cycle the pressure in the first load chamber between atmospheric pressure and 30 millitorr, for example, and in the second load chamber between 30 millitorr and operating vacuum such that a drum could be loaded/advanced in only about three minutes.

It will be appreciated that the use of two, or more, unload chambers have the same advantages as two, or more, load chambers. Accordingly, first and second unload chambers 144 and 154, respectively, would be constructed and operated in the same manner as the two load chambers. It will also be appreciated that additional time benefits may be obtained by using additional load and unload chambers.

Another benefit of multiple load and unload chambers is cost savings in acquiring the pump equipment required. It can be expensive to provide sufficient pumping capability to rapidly cycle between atmospheric pressure and operating vacuum. It is substantially less expensive to provide pumping capability between atmospheric pressure and some intermediate pressure, and between intermediate pressure and operating vacuum. Breaking the cycle into multiple load and unload chambers will also improve the

It will be appreciated from the foregoing that appropriate means must be provided for receiving rotatable drums 24 within the various chambers. Appropriate means are also required for advancing the substrate-carrying drums into the at least one load chamber, through the at least one processing chamber, and into the at least one unload chamber. Presently preferred means for receiving and advancing rotatable drums and substrate mounted thereon are illustrated in schematic form in Figure 4, which is a cross-sectional view of processing chamber 40 taken along the lines 4-4 of Figure 1.

Figure 4 depicts the support of drum 24 upon a frame assembly 57 (best seen in Figure 2) having spaced apart rails 56 mounted parallel to one another. Rails 56 are supported by rotatable pulleys 58 mounted on a track 59. Track 59 spans the length of serial sputtering system 20 so as to provide passage for each frame assembly 57 and supported drum 24 from one end of the system to the other. Some or all of pulleys 58 may be motorized (not shown) so as to move the frame assemblies and drums supported thereon from one chamber to the next. One of ordinary skill will readily appreciate in light of the teachings herein that many alternative means for advancing the substrate-carrying drums might be provided in lieu of the frame and pulleys illustrated.

It may also be desirable to provide a channel 60 along the top of the serial sputter coating system for receiving an extended portion of shaft 62 running through the center of drum 24. This arrangement will assist in stabilizing the drum 24 as it advances from chamber to chamber.

At the appropriate time, a drum and associated substrate is advanced to the center of the appropriate processing chamber. In order to effect deposition and formation of a thin film, the drum must rotate past the cathodes 36 and ion sources 38. Figure 4 illustrates a presently preferred means for rotating drum 24. Figure 4 illustrates the use of a gear 63 that is capable of being raised or lowered so as to engage or disengage a corresponding socket 64 on the underside of drum 24. After engagement of gear 63 in socket 64, further raising of the gear will cause the entire drum to be raised off of frame 57 so that the frame will not apply any frictional impediment to rotation of drum 24. Rotation of gear 63 may then be commenced through operation of a suitable motor assembly 66, resulting in the coupled rotation of drum 24, which in turn rotates substrate mounted thereon past cathode 36 and ion source 38. Upon completion of the thin film deposition and formation sequence within the processing chamber, gear 63 is lowered to its starting position, replacing drum 24 firmly upon the frame 57 and associated rails 56. As shown in Figure 4, the motor assembly is preferably positioned outside the processing chamber. Space to accommodate the motor assembly is preferably provided by mounting

As explained above with references to Figures 1-3, each of the processing chambers contains at least one linear magnetron sputtering device as described in U.S. Patent No. 4,581,095. Accordingly, at least one ion source reaction zone and at least one sputtering cathode deposition zone will typically be present within each processing chamber. The ion source reaction zone and the sputtering cathode deposition zone are atmospherically separated from each other within the chamber. It is important to ensure that excess oxygen in the vicinity of the ion source does not enter the sputtering cathode deposition zone. The linear magnetron sputtering process also requires an effective cathode shutter to allow burndown between layers.

Figure 5 illustrates a top view of a presently preferred configuration for a processing chamber containing both an ion source processing region and a sputtering cathode processing region. As shown, pumps 70 are preferably positioned on each side of the ion source 38 to pump away the excess oxygen. These pumps are preferably turbo-pumps. Baffles 72 are also positioned within the processing chamber to further isolate the ion source processing region. The baffles may extend slightly into the chamber but are preferably pivotable to be pivoted out of the path of the drums (shown in dotted line) during the time when the drums are being advanced through the chamber. The sputtering cathode 36 is preferably isolated in a box 37 which can be shuttered with a sliding shutter 39. It is desirable to mount the ion source to a narrow door 43 between pumps 70 and to mount the cathode, box, and shutter to another door 41 to allow easy access to these components.

From the foregoing, it will be appreciated that the present invention provides substantially improved methods and apparatus for effecting DC magnetron sputtering by increasing the relative amount of time spent in the deposition of thin films, while decreasing the relative amount of time spent loading and unloading the substrate into the processing chamber. The present invention also substantially reduces the relative amount of time spent establishing a vacuum and stable operating conditions for magnetron sputter devices within the processing chamber. Although some time will be required to advance drums and associated substrate from one chamber to the next and initiate rotation of the drums within the processing chambers, perhaps on the order of 1 to 2 minutes, most of the activities other than actual deposition of material onto the substrates will be performed at the same time as deposition is occurring. This will result in extremely significant improvements in the efficiency of the apparatus of the invention in contrast to the apparatus utilized in Patents No. 4,851,095 and No. 5,225,057.

It will be appreciated that the present invention may be embodied in other specific

embodiments are to be considered in all respects only as illustrative and not restrictive, and the scope of the invention is indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. A continuous sputter coating system, comprising:

at least one vacuum processing chamber, each of said at least one processing chambers being in serial communication with adjacent processing chambers, and each processing chamber including:

means for receiving a rotatable drum within the processing chamber, said drum adapted for mounting substrate thereon;

at least one linear magnetron sputter device for sputtering at least a selected material onto said substrate; and

means for rotating said drum within said processing chamber such that said substrate is rotated past said at least one linear magnetron sputter device;

at least one load chamber, said at least one load chamber being in serial communication with the first of said at least one processing chambers;

at least one unload chamber in serial communication with the last of the at least one processing chambers; and

means for advancing the drum and substrate mounted thereon from the at least one load chamber, through each of the at least one processing chambers, and into the at least one unload chamber.

2. A continuous sputter coating system as defined in Claim 1, wherein

the first of the at least one processing chamber is separated from the load chamber by a sealable door, and the last of the at least one processing chamber is separated from the unload chamber by a sealable door, so that a vacuum may be maintained within the at least one processing chamber independent of the pressure within the load and unload chambers; and

further comprising:

means for independently controlling the pressure within the load chamber;

means for independently controlling the pressure within the unload chamber; and

means for independently controlling the pressure within the at least one processing chamber.

3. A continuous sputter coating system as defined in Claim 1, wherein there are a plurality of processing chambers, and wherein each of the plurality of processing chambers is separated from adjacent processing chambers by a movable barrier.

4. A continuous sputter coating system as defined in Claim 1, wherein there is one load chamber and one unload chamber.

5. A continuous sputter coating system as defined in Claim 1, wherein there are two load chambers and two unload chambers.

6. A continuous sputter coating system as defined in Claim 1, wherein there are three processing chambers.

7. A continuous sputter coating system, comprising:

a plurality of vacuum processing chambers, each of said processing chambers including:

means for receiving a rotatable drum mounted within the processing chamber, said drum adapted for mounting substrates thereon;

at least one linear magnetron sputter device adapted for sputtering at least a selected material onto said substrate; and

means for rotating said drum within said processing chamber such that said substrate is rotated past said at least one linear magnetron sputter device;

said plurality of processing chambers being in serial communication so that a drum can pass successively through each of said chambers for sputtering deposition onto the substrates mounted thereon;

at least one load chamber, said at least one load chambers being in serial communication with the first of the plurality of processing chambers,

each of said load chambers having a sealable door at each end thereof and having means for independently controlling the pressure within said load chamber, so that a desired pressure may be established within the at least one load chamber independent of the raising and lowering of pressure within other chambers of said sputter coating system;

at least one unload chamber, said at least one unload chamber being in serial communication with the last of the plurality of processing chambers,

each of said unload chambers having a sealable door at each end thereof and having means for independently controlling the pressure within said unload chamber, so that a desired pressure may be established within the at least one unload chamber independent of the raising and lowering of pressure within other chambers of said sputter coating system; and

means for moving the drum and substrate mounted thereon from the at least one load chamber, through each of the plurality of processing chambers, and into the at least one unload chamber.

8. A process for forming thin sputtered films on substrates, comprising the steps of:

providing at least one vacuum processing chamber in serial communication with at least one load chamber and at least one unload chamber,

said vacuum processing chamber including means for receiving a rotatable drum, at least one magnetron sputter device adapted for sputtering a selected material onto substrate supported by said drum, and means for rotating said drum within said processing chamber such that said substrate is rotated past said at least one linear magnetron sputter device;

said load and unload chambers being sealable from the at least one processing chamber so that a vacuum may be established and maintained in the load and unload chambers independent of the pressure in the at least one processing chamber;

establishing a vacuum in the at least one processing chamber;

cycling the load and unload chambers between atmospheric pressure and the pressure within the processing chamber in order to permit the advancing of drums and substrate mounted serially through the at least one load chamber, each of the at least one processing chambers, and the at least one unload chamber; and

advancing said drums and substrate in coordination with the cycling of the pressures within the load and unload chambers.

9. A process for forming thin sputtered films on substrates, comprising the steps of:

providing at least one vacuum processing chamber in serial communication with at least one load chamber and at least one unload chamber, said vacuum processing chamber including means for receiving a rotatable drum, at least one magnetron sputter device adapted for sputtering a selected material onto substrate supported by said drum, and means for rotating said drum within said processing chamber such that said substrate is rotated past said at least one linear magnetron sputter device; said load and unload chambers being further provided with sealable doors at each end so that a vacuum may be established within the load chambers, processing chambers, and unload chambers independent of other chambers;

sealing the door between the load chamber and the first of the at least one processing chambers;

sealing the door between the unload chamber and the last of the at least one processing chambers;

establishing an operating vacuum within each of the at least one processing chambers;

establishing operating conditions with respect to the at least one magnetron sputter device within each of said at least one processing chambers;

introducing a rotatable drum having substrate mounted thereon upon which a thin film is to be deposited into the first of the at least one load chamber;

establishing a vacuum within the at least one load chamber;

advancing the drum and substrate from the at least one load chamber into the first of the at least one processing chamber;

rotating said drum within said processing chamber to thereby deposit the desired thin film onto substrate;

after deposition is complete, opening the door between the last of the at least one processing chamber and the first of the at least one unload chamber;

advancing the drum and substrate into the at least one unload chamber; and

repeating the foregoing steps so as to substantially continuously advance drums and substrate through the at least one processing chamber without disrupting the operating vacuum within said processing chamber and without disrupting operating conditions of the at least one magnetron sputter device.

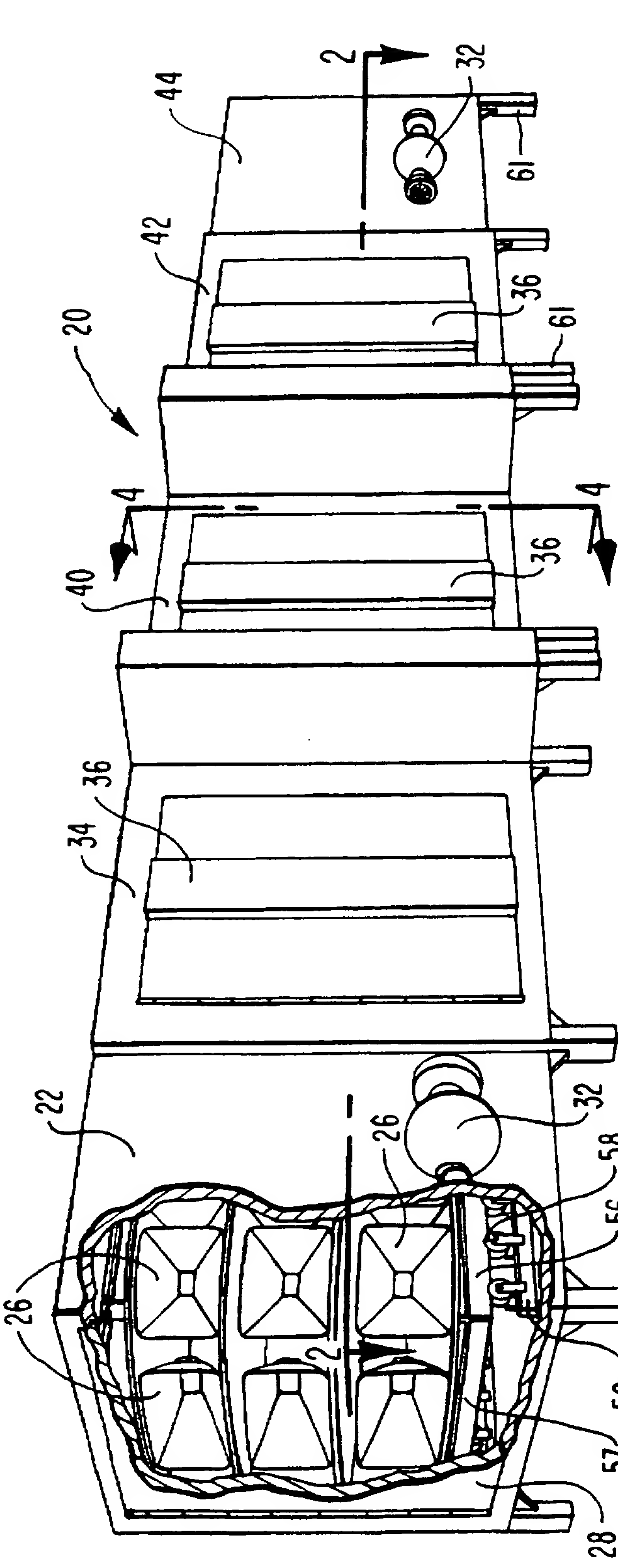


FIG. 1

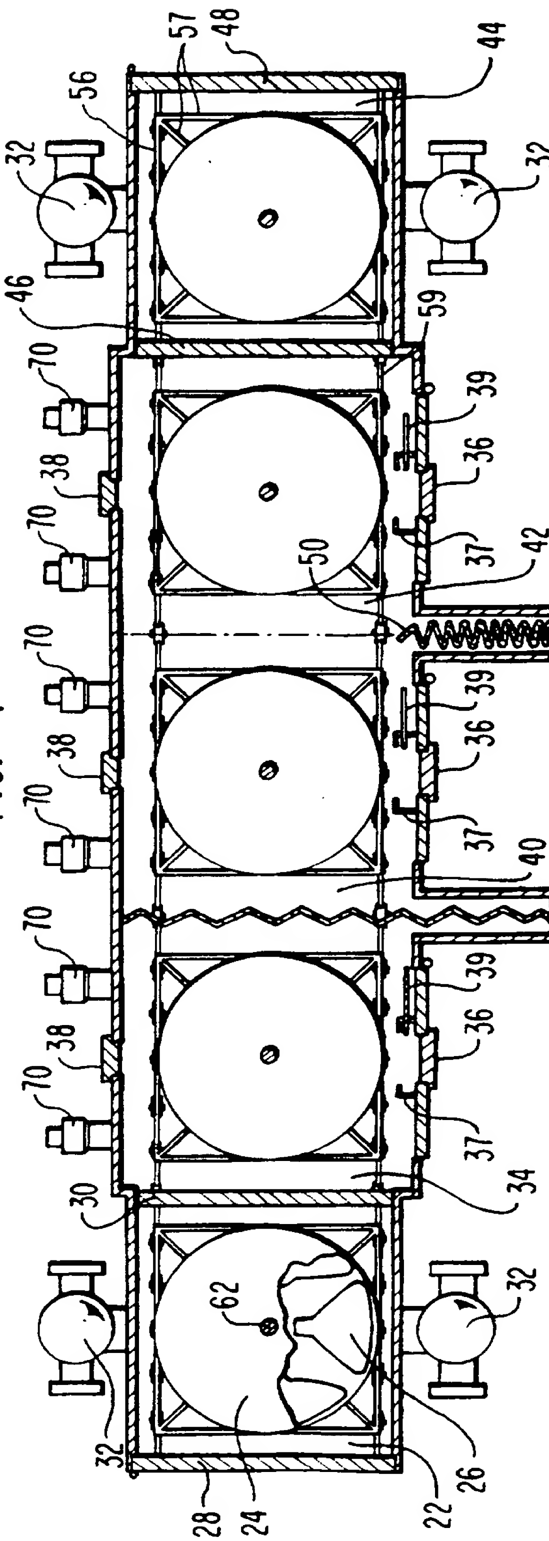


FIG. 2

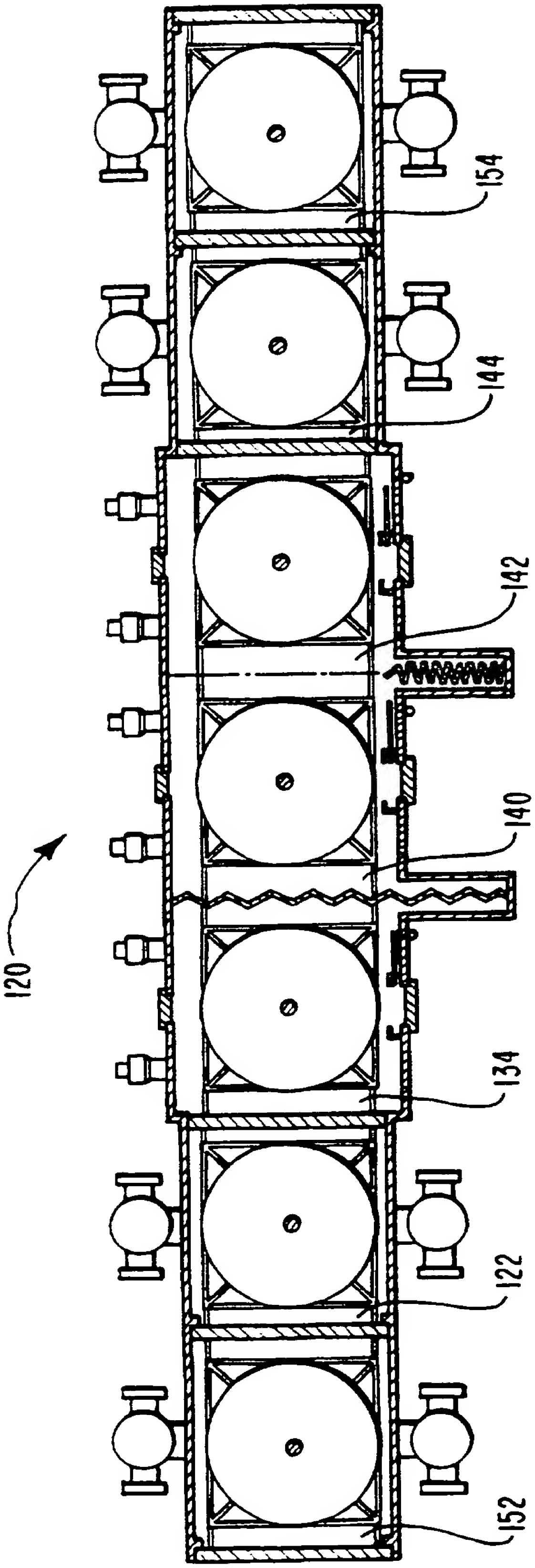


FIG. 3

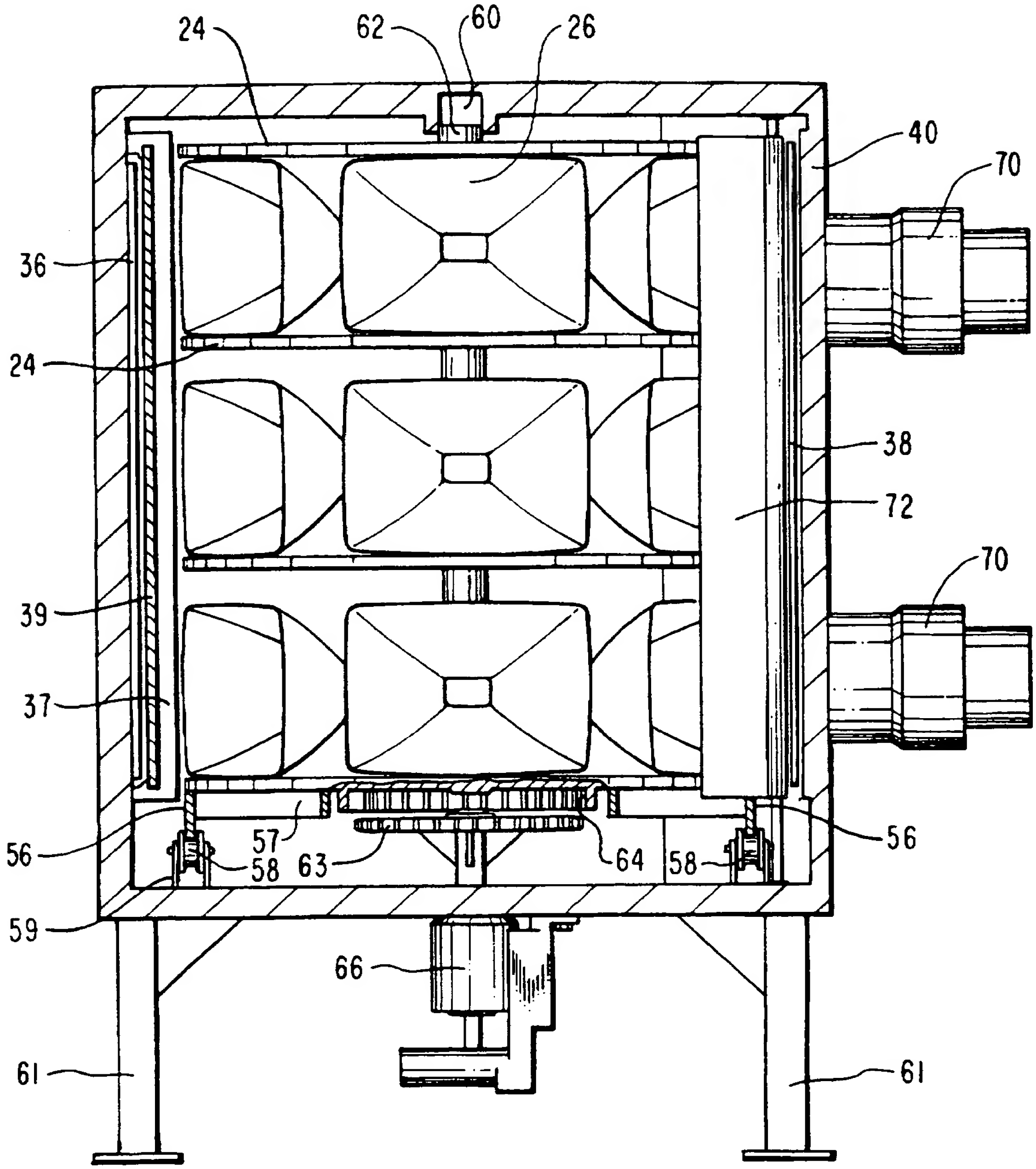


FIG. 4

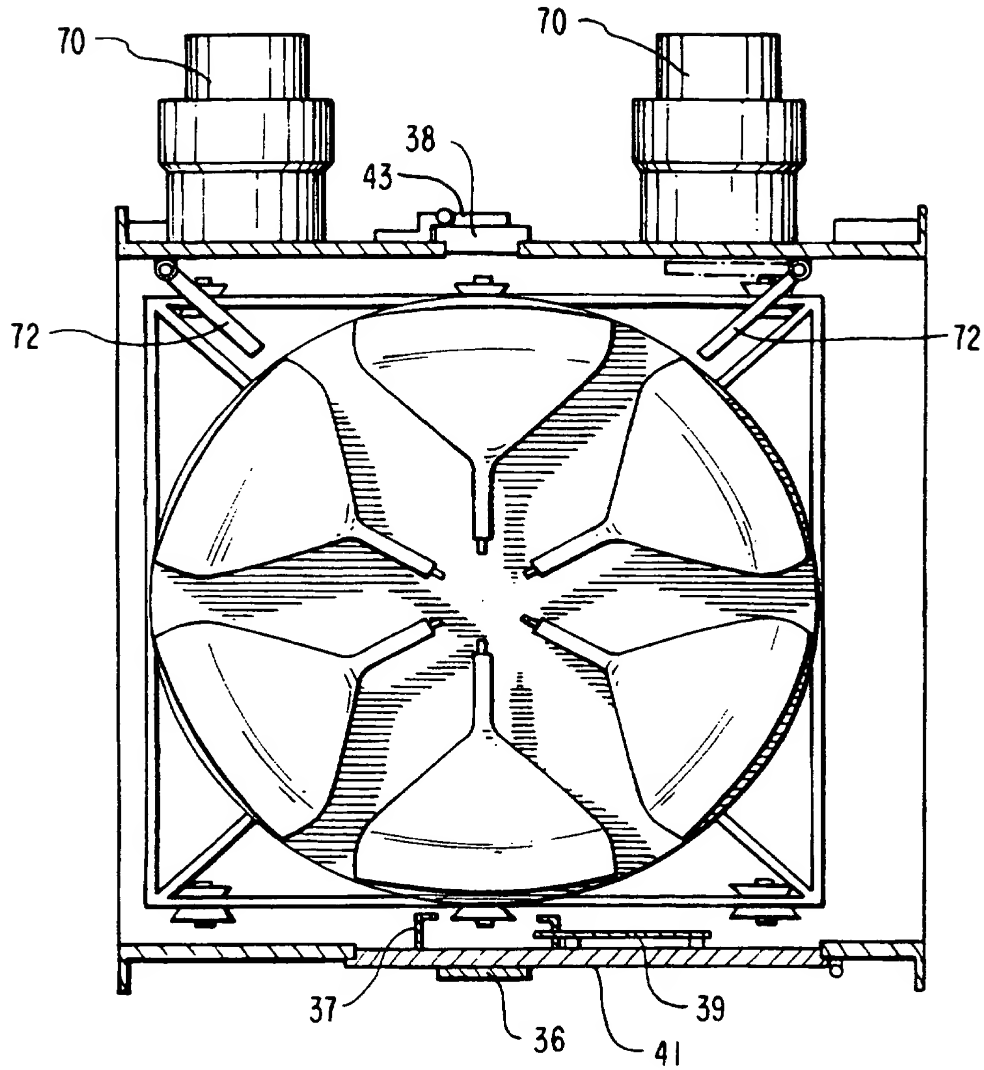


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/00654

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :C23C 14/56
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 204/192.12, 298.07, 298.15, 298.19, 298.23, 298.25, 298.26, 298.27, 298.28

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,340,454 A (SCHAEFER et al) 23 August 1994, See Abstract; Column 2 lines 39-68; Column 3 lines 1-35; Column 4 lines 1-11.	5
Y	US 4,975,168 A (OHNO et al) 04 December 1990, Column 4 lines 63-68; Column 5 lines 1-30.	2,4,7,8,9
Y	US 4,877,505 A (BERGMANN) 31 October1989, Figure 4; Column 7 lines 26-38.	1,4,6,7,9
Y	US 4,814,056 A (WELTY) 21 March 1989, Column 4 lines 34-58; Column 6 lines 39-42.	1,3,4,6,7 8,9
Y	US 4,790,921 A (BLOOMQUIST et al) 13 December 1988, Column 7 lines 25-68; Column 8 lines 1-50; Column 8 lines 50-62; Column 10 lines 34-57.	2,3,4,6,7, 8,9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 MARCH 1997	08 MAY 1997

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231
Facsimile No. (703) 305-3230

Authorized officer
RODNEY MCDONALD
Telephone No. (703) 308 - 3807

Form PCT/ISA/210 (second sheet)(July 1992)★

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

204/192.12, 298.07, 298.15, 298.19, 298.23, 298.25, 298.26, 298.27, 298.28